TOOLS FOR AGRONOMISTS

INTRODUCTION

It is generally accepted that significant reductions in soil organic matter content have occurred in agricultural field soils under high input farming systems, typically characterised by first world food production methods and that consequentially crop yields will ultimate move from the plateauing, currently experienced, to decline [1-9]. Concerns relating to soil organic matter loss and negative impacts on crop yield resulted in the UN FAO declaring 2015 the International year of Soil (FAO, 2015). In some areas of UK farming this alarming negative yield phenomenon is expected to materialise within one generation at a time when UK agriculture production is expected to increase with demands for greater UK self-sufficiency that will require a move to “sustainable intensification” (Royal Society, 2009) . Methods to mitigate impending decline in crop yields need urgently to be considered, in the light of major advances in soil and crop sciences, and where possible implemented now.

Critically the evolution of soils is slow [10], and if soil organic matter content is allowed to dip below a critical minimum limit the process of regeneration may take many decades[11]. With our greater understanding of plant and soil interaction and innovation in farming practises we can, however, enhance the partnership between plants and soils to raise soil organic matter and increase the quantity of plant available nutrients to reduce chemical and water inputs in industrialised food production [12]. The understanding of the interaction of soil microbes and plants within a commercial rotation plan is critical in increasing plant efficiency in uptake of nutrients and water.

Microbes and plants are intimate partners in virtually every life process.

It has been known for a long time that soil micro-organisms contribute to functional soils and that they are indispensable for plant survival as they act upon soil’s physical or chemical properties, or directly by interacting with plant roots (Orgiazzi et al., 2016).

The majority of plants, strictly speaking, do not have roots; they have mycorrhizas.

Within the long list of soil micro-organisms that contribute to functional soils, one of the most characterised, and arguably the most important, are Arbuscular Mycorrhizal Fungi (AMF) [13, 14]. These micro-organisms symbiotically associate with plant roots and extend a vast network of fungal hyphae into the soils that function as an extensive secondary root system [15]. Research to understand the value and function of mycorrhizal fungi has been a global endeavour with groups across the world contributing to more than 60,000 technical papers and articles over the last fifty years representing many tens of millions of pounds in investment.

It is well documented that one major function of AMF in soils is to significantly enhance plant phosphorus uptake [16-18]. But more recent work has shown that enhanced organic and mineral nitrogen and micronutrient uptake is also significant, together with locking essential soil carbon in the upper soil horizons [19-21].

Strictly speaking, 90% of land plants don't have roots they have a 'mycorrhizae', a term composed of ‘mycor’ meaning fungal and ‘rhiza’ denoting root, describing this ubiquitous symbiotic union of roots and beneficial soil fungi [22].

The symbiotic relationship is further enhanced and supported by soil bacteria, making microbiologically rich communities most efficient in nutrient cycling [23].

Beneficial soil bacteria

Beneficial soil dwelling bacteria are abundant and genetically diverse. A group collectively known as plant 'growth promoting rhizobacteria' (PGPR) that actively colonise the surfaces of plant roots, termed the rhizosphere, are part of this complex community. PGPRs act to mineralise nutrients, produce plant growth regulating phytohormones and fix nitrogen from the air into ammonia- the actual product of the highly energy demanding chemical Haber-Bosch nitrogen fertiliser production process (Erisman et al., 2008). Although able to live independently of plants, PGPR are known to work synergistically as a consortium associated with roots and, more recently, with mycorrhizal fungi to provide plants with essential nutrients, stimulating the plant's growth and immune system and modulating stress responses [24-26].

Nutrient acquisition by PGPR is achieved via nitrogen fixation [27, 28], solubilisation of phosphates from recalcitrant but often abundant source minerals in soils [29] and other locked up soil mineral nutrients [30] and by the production of chelating agents [31-33].

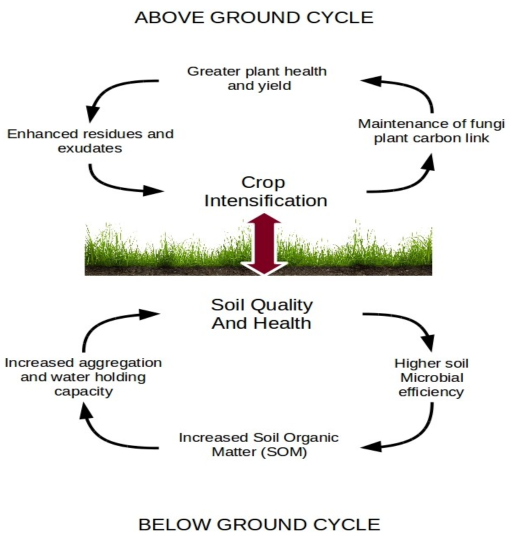
The phytohormones (chemicals that regulate plant growth) these bacteria produce include auxins and cytokinins that act to increase the growth of plant roots and shoots respectively, increasing the surface area for nutrient absorption and photosynthesis [30, 34]. These bacteria, much like mycorrhizal fungi, can critically induce systemic resistance in plants against both abiotic and biotic stresses by producing stress-related enzymes such as ACC deaminase decarboxylase to reduce ethylene levels, which at high levels reduce the plant's ability to overcome stresses, but also increasing the plant's abscisic acid levels to prevent water loss in drought situations [35, 36].

Via the activation of defence-related genes and encoding enzymes, PGPR produce and release antimicrobial substances to act against plant disease causing pathogenic bacteria, fungi and insects [37, 38]. The presence of these bacteria in the rhizosphere competitively excludes potential soil pathogens as they compete for space, nutrients etc. [39, 40].

Biological Agronomy

The modern agronomist requires a detailed understanding of soil management as well as access to practical tools to offer advice to farmers in relation to the importance and value of active microbial resources within their soils, together with practical advice on how to modulate farming rotations including methods of inoculation to enhance soil microbial communities.

The plant / soil carbon link:



AMF fungi are obligate symbionts, meaning the fungus requires a living host plant to survive [15]. Photosynthetically fixed carbon is shared by the plant with its fungal partner in exchange for nutrients and water accessed and transferred from fungus to plant [15].

SMART ROTATIONS seek to maintain a carbon link between microbial communities and host crops during commercial production of food and forage. The tools outlined here aim to assist farmers and agronomists on the appropriate use of microbial management and interventions in farming.

All life depends upon the *soil.*

There are three factors that comprise quality soils: soil chemistry, soil physics and soil microbiology.

Soil Chemistry: The green revolution technologies, refined and widely adopted from the 1940's, notably through the synthetic production and mass application of nitrogen have supported a rapid increase in field crop production [41, 42].

Prior to the industrial revolution, the primary energy input for agriculture was the sun; photosynthesis enabled plants to grow, and plants served as food for livestock, which provided fertiliser (manure) and muscle power for farming.

However, the calorific demand from land under production required additional energy to be used to drive the system. During the period of industrialisation and consolidation of agriculture this was derived from chemical fertiliser intervention, which itself requires significant amounts of energy from the use of fossil fuels in the production and/or mining of nitrogen, phosphorus, potassium and other macro-elements. The exhaustion of phosphate rock, the raw material for the production of superphosphate, in the next 70-100 years represents a major threat to maintaining crop yields in the 21st Century as increasing demand from tropical agriculture reduces SP fertilizer availability and increases prices (Cordell and White, 2015)

In concert with the use of high input systems the farming supply chain, including plant breeders, agro chemical producers and agronomy advisors have focused on tuning the farming 'value chain' to maximise output from this method of farming.

The noted plateauing of farming yields, after many years of acceleration due to the combined efforts of the farming supply chain is sobering, but this is only one symptom in a series of other detrimental soil factors that have become recognised as a consequence of this approach to farming over recent years. Unintended consequences in water use, soil degradation, and chemical run-off have had serious environmental impacts beyond the areas cultivated [43-45].

The slowdown in yield growth that has been observed since the mid-1980s can be attributed, in part, to the degradation of the agricultural resource base [44]. These environmental costs are widely recognised as a potential threat to the long-term sustainability and replication of the green revolution approach [46]. More important still is the fact that the very functioning of the green revolution system relies on soil organic matter being present in the soils at sufficient quantities. Within a few hundred years of man harnessing the land for refined food production soil organic matter has reduced dramatically [47].

Soil Physics: Formally described as the study of properties and processes, soil physics deals with the dynamics of physical soil components and their phases as solids, liquids, and gases. It draws on the principles of physics, physical chemistry, engineering, and meteorology. These processes become ever more important as most farmers require an understanding of agroecosystems.

The discipline has been extended in recent years to look at agricultural field management, with a focus on contour ploughing, tramline control, direct drilling and planting to reduce effects of rain run-off responsible for top-soil erosion and the subsequent degradation of the functional strata in the soil [48]. Other interventions have included the addition of organic matter (e.g. biochar) to increase air porosity and carbon sequestration [49]. Much of this work seeks to reduce the impact of modern farming practices to slow down the degradation of soils.

Soil Microbiology

The final domain of quality soils is the inherent microbiology. Theise ecosystems of plants, animals, bacteria and fungi act to turn over organic matter, mineralise nutrients into plant available form and transport these directly into the plant roots [50]. Classically plant researchers have focused on the *rhizosphere*, the thin area close to the physical roots of a crop, where dense communities of soil micro-organisms gather to feed on plant exudates as the main area of soil activity [51]. Today, new scientific tools and technologies allow for the study of microbial diversity and individual cellular pathways, via microbiomics, gemomics and metabolomics (Prosser, 2015), meaning that the focus can be broadened to the interaction between plants and microbial communities. Plant science in farming can now consider entire plant systems in unison with their microbial partners.

The mycorrhizosphere is the region around mycorrhizal roots that also encompasses the soil colonising fungal phase a mycorrhizal fungus in which nutrients released from the fungus increase the microbial population and its activities. This region is significantly larger than the rhizosphere and a fully 'mycorrhized' plant is considered to have in excess of a 700 fold increase in root surface area in comparison to a non-mycorrhized plant [52].

Beyond the benefits of increased effective absorption area this network also extends into the ecosystem in which other micro-organisms act to support the host plant (Johansson et al., 2004).

The concept of 'plant efficiency' is important in modern farming. A plant with a well-developed mycorrhizal fungal network, together with their associated bacteria, is better able to gather nutrients and water, but this network also interlinks with other plants as a common fungal root system [53]. Recent work has shown how this network also uses chemical signalling to trigger up-regulation of systemic resistance to soil pathogens and other biotic stress factors in AMF host plants [54-56]. The management of soil microbes through practice and intervention will have a direct effect on the chemical demands in farming considering both biomass and plant protection [57, 58].

A first world problem

The calorific demand from the land in modern farming cannot be supported through organic farming practices alone; there is need to use integrated management practices that will include chemistry and microbiology in farming. In the light of recent understandings of the detrimental effects of high input systems of chemicals on soils and our greater understanding of the how to manage soil microbiology, there is significant scope to rebalance the modern farming system [58].

In this new era farming agronomists need to understand soil factors and be able to offer advice on the management of soils over a rotation plan, to ensure that soil organic matter is maintained and enhanced through the sympathetic use of inputs, innovation in farming practices and microbial interventions.

Modern farming practises

A number of factors in modern farming reduce or break the plant fungus / carbon link [58]. Principle amongst these is the cultivation of non-mycorrhizal plants. Although mycorrhizal fungi associated with 80% of land plants and 90% of agricultural plants notable exceptions include members of the *Brassicaceae and Amaranthaceae [15].* **SMART ROTATIONS** do not imply abandoning these crops but do promote the concept of either inter-cropping with low level associating plants, such as clover, which has a net nitrogen soil influx benefit, or the inoculation of follow-on crops with mycorrhizal fungi.

Additionally, the inoculation of non-mycorrhizal plants with PGPR can be a way to colonise these crops with growth promoting microorganisms, therefore boosting the beneficial microflora during the growth of these types of crops. Brassica plants for example are known to be notoriously soil nutrient demanding (greedy) and therefore would can benefit from the nutrient acquisition abilities of PGPR. As these types of bacteria work synergistically with mycorrhizal fungi, they are ready to partner with the fungi that are subsequently inoculated into the soil.

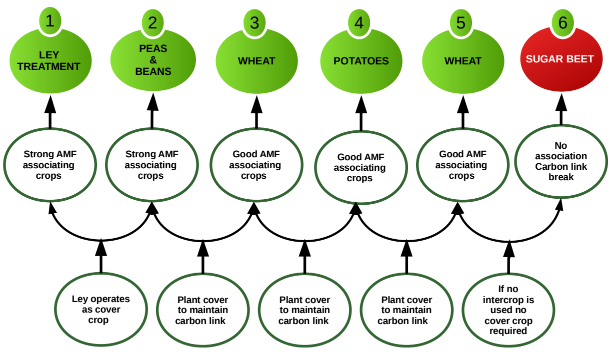
A fundamental principle of **SMART ROTATIONS** is to eliminate breaks in the plant / fungus carbon link. This key principle requires agronomists to consider not only the management of crops but also the management of the microbial backgrounds in soil through 'method' or 'intervention'.

Mitigation by method

For the sake of illustration a six year rotation programme is presented in Figure 2, comprising a resting ley period with two seasons of vegetables interspersed with wheat and ending in sugar beet, before repeating.

In the illustrated rotation sugar beet is shown in the red circle as the only non-AMF associating crop within the rotation. This crop breaks the carbon link for the longest period and some consideration should be given to the possibility of intercropping with a legume, possible clover, as a source of green manure and carbon support for the soil microflora particularly AMF. The inoculation of PGPR will ensure beneficial microbial association with the sugar beet crop, and ready to work in synergy with the mycorrhizal fungi added to the soil with subsequent crops.

Fig. 2: Microbiology management through farming method.

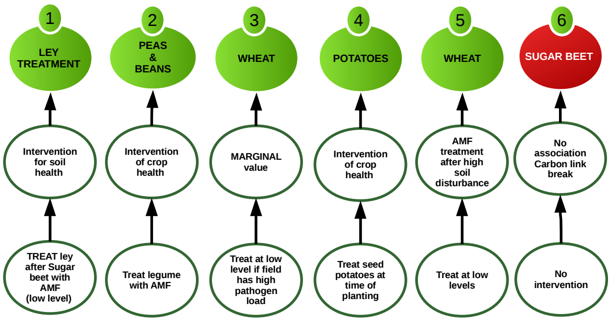


Mitigation by intervention:

Although AMF are complex organisms they can be cultivated and commercial inocula are available to be used in farming as seed treatments. Suitable for application with most farming seed drills this inoculum is best applied under or close to the target seed to allow rapid signalling between plant and fungus to promote early colonisation.

The inoculation approach needs to take into account a number of factors known to affect colonisation, such as plant varieties and soil status as well as economics. An 'inoculation decision framework' is presented in Figure 3 to quantify the value of the intervention with mycorrhizal fungi within a rotation programme.

Fig. 3: Microbiology management through use of inocula



Inoculum quality:

The method of defining product efficacy in relation to bacteria products is well documented in literature. The culturing of these organisms can be undertaken in flasks or bioreactors that control the pH status of the media, temperature and absorbed oxygen to maximise growth rates. Typically bacterial inocula are sold with reference to colony forming units (CFU) per ml. Due to the vigorous growth rate of these organisms, the actual CFU per ml can be vast e.g. 10^{8} – 10^{11}.

A well characterised inocula will have growth curve published that will map the maximum yield point of cells that are considered more resilient before the bacteria are harvested. Additional information will show the effective shelf life of these products. There is usually a significant reduction in CFU when moving from a liquid culture to a more stable and potentially useable dry carrier form in farming. Field trials undertaken on different bacteria suggest that seed drilled crops with even distribution of inoculum through seed coulters, that a rate of 10^{5} CFU per seed should be sufficient.

Unlike bacteria mycorrhizal fungi are very slow growing organisms, taking many months to produce in quantity. Whilst bacteria are self-contained organisms, mycorrhizal fungi have in effect three propagules (fungal structures within roots) with which they can create a symbiosis with a plant. The most highly prized propagules of AMF are the spores. Each spore contains all the genetic material of the fungus and is in many respects a self-contained capsule with a potentially long life-span in the soil. The fungal network itself, the ‘hyphal network’, can also be used to confer a mycorrhiza (plant fungi union) when dried, this propagule is shorter lived but in some circumstances can be quick to colonise. Finally the cut up root fragments of the host plant used to cultivate the AMF can be used to establish the symbiosis.

The industrial quality standard that is generally used for mycorrhizal fungi is the Most Probably Number (MPN) measure. As a bio-assay, the MPN test is undertaken on host plants inoculated with progressively lower doses of AMF in sterile growing media. Once mycorrhizae are established, host plant roots are stained and intraradical AMF structures are counted. Methodology and scoring for this process are well defined in scientific literature. The output of this quality assessment is a number from 1 – 1.6 million propagules per litre of inoculum. It is true that ten years ago much variation existed in the quality of fungal inoculum, in terms of the diversity, formulation and efficacy with typically inoculum levels falling below 50K propagules a litre. As the production science has improved and best practise has developed it is now not unrealistic to demand and multiple species inoculum with an MPN of 500K or more when planting.

It is true that in perfect condition a single propagule of AMF can colonise a host plant and evolve to create a substantial fungal network of support for the plant. But unlike bacteria where 10^5 CFU per seed is possible during drilling within 1 linear metre of drilled seed number between 10-150 propagules are going to be more common place when calculating fungal loading.

Inoculation decision framework:

The value of inoculation of a crop at time of planting requires consideration of both crop and soil factors. Remembering that the goal is management of the soil microflora, non-AMF crops may be considered as having no merit in this system, as cultivation of these plants breaks the carbon link principle of **SMART ROTATIONS**.

It is possible, however, to maintain this link through the use of a legume intercrop such as clover. In the event that intercropping is not desirable due to issues of contamination, harvest, costs etc., the field may be considered as having a higher ranking for inoculation with AMF for the follow on crop. Equally there is value in inoculating with PGPR on these non-mycorrhizal crops to compete for rhizosphere space, support the crop with enhanced microbial communities.

Fig. 4: Plant and soil factors for consideration when inoculating.

The major plant and soil factors to be considered are outlined in this model. It should be noted that some of these factors are temporal, that is they relate to the previous crops rather than the current planting.

The inoculation decision framework is based on a weighed score card approach, in which plant and soil factors are given a score (0-5). When summed and processed this model offers a recommendation of one of three outcomes: TREAT, OPTIONAL or DO NOT TREAT (Figure 4).

Crop AMF dependency (0 or 1): Within the score card this factor is considered 'boolean' that is to say is either a 0 or a 1 representing whether the crop will maintain the carbon link with fungus or not.

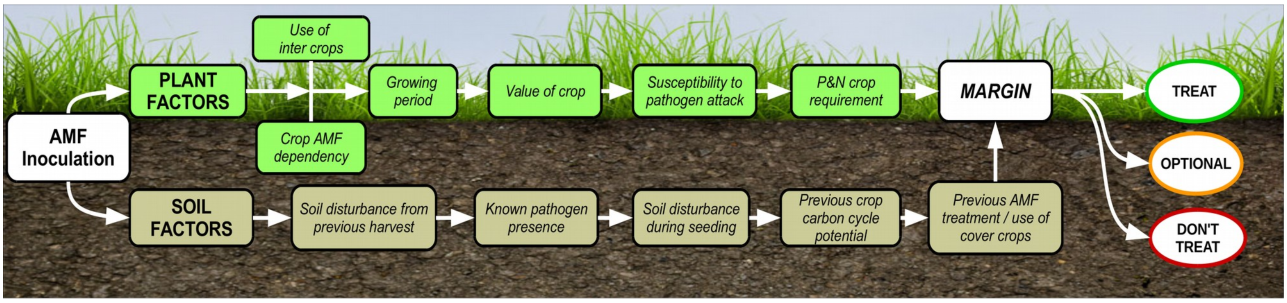
As this is a primary crop if this is a non-associating crop all plant factors will subsequently be set to zero. In the event an intercrop is being used to maintain the carbon link, soil factors will be supported by the intercrop, and these will still contribute to the field scoring.

General Note: Although there are specific vascular plant families that do not associate with AMF, notably *Brassicaceae* and *Amaranthaceae,* plant breeding up until recently has not focussed on microbial association of plants and in some cases plants have begun to tune out this relationship in preference to compatibility to high input fertigation regimes [59]. Where information is available on the AMF association crops, by family and variety, this should be considered in the selection process.

This model suggests that agronomists advising on building soil health should recommend for intercropping with leguminous plants where possible to maintain the plant / fungal carbon link. In recommending this course of action it is recognised that the demand on the land from the intercrop can have effects on the primary crop yield.

Growing Period (0-5): Under the correct growing conditions the 'germination' of AMF spores and the subsequent hyphal progress, to initially colonise a host plant and then to propagate into the soil in the quest of nutrients and water, is relatively quick, with colonisation and symbiosis occurring within two to three weeks. The characteristics of a fully developed hyphal network, the 'fungal root system', will depend on the soil profile and nutrient and water requirement of the plant host. It may extend many feet into the surrounding soil. This evolution of active root area, beyond what is traditionally considered the rhizosphere, can take months and therefore crops with long growing periods have a greater capacity to drive the carbon cycle and to develop both scope and biodiversity of the fungal network.

Value of crop (0-5): The intervention with AMF in a farming rotation through the use of inocula must take into consideration the return on investment in terms of: yield, pathogen suppression and soil value.



For crops that are highly AMF associating, for example herbal leys, leguminous cover crops, which have high seed densities and are usually planted for longer period low levels of AMF, typically 2 – 4 litres per hectare can be applied at a lower cost.

For higher value crops, for example carrots or asparagus, which are drilled with machinery able to precision-dose and apply granular fertilisers, direct application of AMF can be considered at rates of 10 – 20 litres per hectare.

Susceptibility to pathogen attack (0-5): *AMF* are well documented in respect for their ability to assist a plant to resist soil pathogen ingress, notably *Furasium*. [60, 61]. The method of protection is not 'cidal' but rather is a barrier process, whereon the colonisation of the fungus of the root cells and the subsequent formation of arbuscular (sites of nutrient exchange within the root cell) limit niches for pathogen entry [52].

More recent work has elucidated that this mode of action is part due to the up-regulation of the plant's induced systemic resistance by the fungus.

P&N crop requirement: Phosphorus (0-5): Plants with high P and N requirements may benefit from enhanced AMF populations [16-21, 62]. It should be noted that soils with readily available P can act to limit the development and uptake of AMF. However, in the event that P is available but N is in short supply the presence of high P in the soil has been shown not to suppress AMF / host partnership development.

Recently it has been shown that with the fungal partner in place, host plants will down-regulate their own P uptake pathways in favour of receiving P via the AMF pathway, implying this strategy as a highly energy efficient mechanism [63].

Known pathogen presence (0-5): Where a field is known to contain a pathogen load in advance of planting, consideration should be given to treating higher value associating crops with AMF and PGPR to enhance plant health and compete for root cell space.

Soil disturbance from previous harvest (0-5): Deep ploughing is known to dramatically disturb established hyphal networks [64]. Although the process is thought also to distribute spores into the soil, if the land is left fallow and moisture and temperature requirements are met, these will germinate and die in the absence of a suitable host plant [65-67]. Deep ploughing or deep soil harvest methods leading to significant soil disturbance have a negative impact on soil health and are ranked accordingly in the score card.

Soil disturbance during seeding (0-5): As above farming practises to limited soil disturbance are general considered to favour the long term development of microbiology communities. Non-till farming systems score low on this metric as these support native AMF communities, while more stringent seeding methods with a higher degree of soil disturbance are scored higher.

Previous crop carbon cycle potential (0-5): The temporal component in considering the use of AMF relates to the ability of the proceeding crop to support the plant / fungus / carbon link. If this is low, i.e. as in the cultivation of oilseed rape, the score card rating is low, indicating a negative impact on the microbial community during this barren period.

Previous AMF treatment / use of cover crops (0-5): This entry denotes whether intervention on the previous season crop did include AMF treatment and / or the nature of the cover crops used to maintain the plant fungus carbon link. A range of 0 - 5 is used to offer a scale for the make-up of the cover crop and its level of associating with AMF.

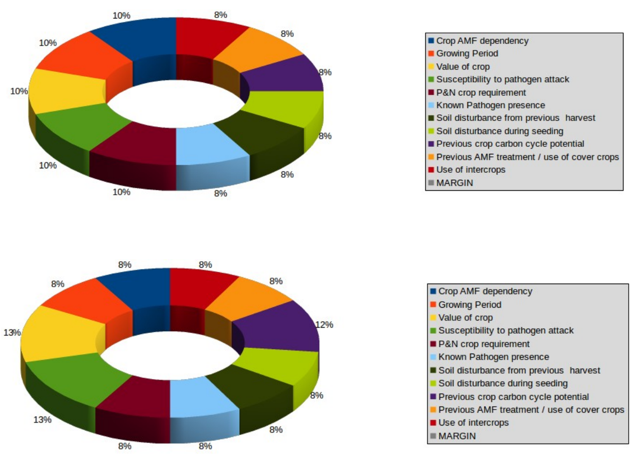
Use of intercrops (0 or 1): This represents a logical condition to confirm whether an AMF associating intercrop is being employed.

MARGIN: Is a measure of the merit of inoculating the crop with AMF after the deduction of the score card result in relation to both crop and soil factors.

Weighted factors:

Although all of the factors outlined have influence on the decisions in relation to rotation selection, farming method and inoculation, they are not necessarily evenly weighted in terms of their significance. In the following modelling crop value, susceptibility to pathogen attack and the previous crop's carbon cycle potential have been weighted at a rate of 1.5 (Figure 5). The first two factors are weighted to increase the significance of the economic value of microbial management.

Fig. : Evenly(a) and weighted(b)factors:



Representations of score card:

In the following example the weighted score card for a herbal ley (cover crop) is presented within the rotation scheme. For simplicity the full pie chart is rationalised below into three sectors illustrating the value that mycorrhizal fungi would offer the plant and soil as well as the percentage recommendation for treatment.

The score card will offer recommendations on treatments as outlined in the table below:

In the Figure 6 for the herbal ley cover crop the score card offers a TREAT recommendation which has been triggered due to the rotation having had a low AMF associating crop previously.

Practically as this crop has a high seed density per metre square of land and the blends are generally highly AMF associating a low application of AMF (2 - 4 kg/ha of inoculum) could be considered as a pure soil treatment.

For the sake of illustration a simplified pie chart is shown where the contributing factor scores for plant and soil have been combined, the red section projective the lack of value from treatment.

Value >50%	Treatment recommended
Value 33-50%	Optional treatment
Value <33%	Treatment is NOT recommended

Ley Mix		Score	Score level	factor	
Plant Factors	Crop AMF dependency	1	(0-1)	1	
	Growing Period	5	(0-5)	1	10.00%
	Value of crop	2	(0-5)	1.5	6.00%
	Susceptibility to pathogen attack	2	(0-5)	1.5	6.00%
	P&N crop requirement	1	(0-5)	1	2.00%
	Use of intercrops	0	(0-1)	1	
Soil Factors	Known Pathogen presence	3	(0-5)	1	4.62%
	Soil disturbance from previous harvest	4	(0-5)	1	6.15%
	Fallow (bare soil)	1	(0-5)	1	1.54%
	Soil disturbance during seeding	5	(0-5)	1	7.69%
	Previous crop carbon cycle potential	3	(0-5)	1.5	4.62%
	Previous AMF treatment / use of cover crops	2	(0-5)	1	4.62%
	TREAT			1	53.23%

Fig. 6. The herbal ley cover crop the score card offers a TREAT recommendation

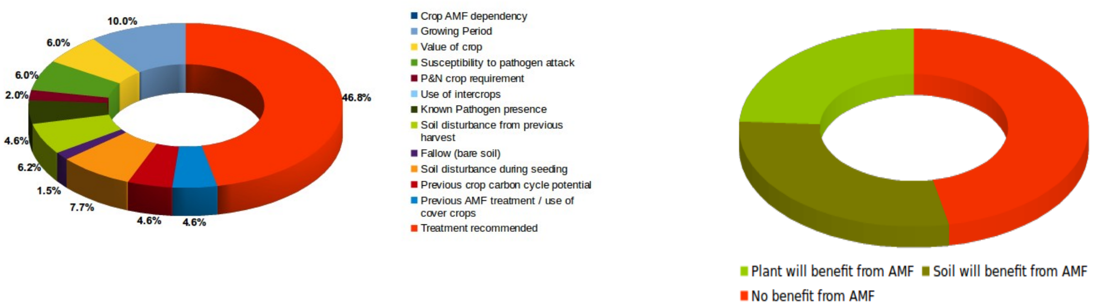


Figure 8. simplified visual for score card

Taking the previously illustrated six year rotation and superimposing the score card on the planting programme options for 'intervention' in building soil microbial health are shown as:

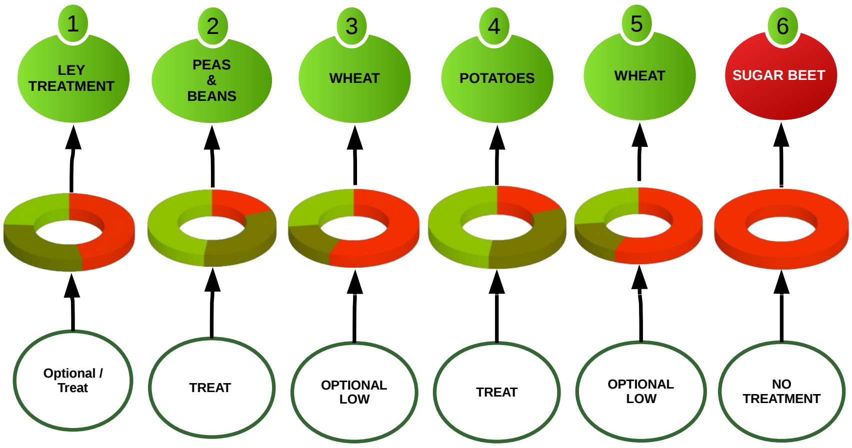


Figure 9. Inoculation according to recommendations using SMART ROTATIONS system

SUMMARY:

A highly biologically active soil is a farmer's ally in the quest to reduce fertiliser inputs, increase plant health, enhance yields and mitigate pathogen attack. Much can be done to achieve this goal by the prudent planning of rotations through crop selection, intercropping and land management.

Equally, due to the development of mass production techniques for beneficial microbes, options for intervention exist where a balance is created between a modulated regime of chemical agro chemical inputs that can denuded microbial communities and strategies of 'replacement'.

It is a matter of fact that there is a substantial body of scientific evidence from around the world that underpin the value soil micro flora offer the soil in relation to yield, crop protection and carbon sequestration. The mode of action of these organisms vary tremendously but selected and manufactured correctly microbial intervention in farming can be deployed using existing seed drills – today.

Although much focus will be on the value of the treated crop and the yield and health benefits that accrue from treatment Agronomists should consider the longer term value of soils when advising farmers on best practice,

Tools to measure microbial activity in the soil, outside the laboratory, do not exist and due to the complexity of the make-up of the communities and the vast genetic complexity of the organism themselves they are not likely to materialise in any form of easy and cheap field assay. With the significant scope of the research that exists that elucidates the critical role in plant / soil interaction these organisms play it is not a leap of faith to offer advice on soil biological management programme.

A soil management programme should seek, at the very least, to ensure soil degradation slows over progressive cycles of intense farming. Preferably agronomists should seek to offer long term soil management programmes that seek to increase organic matter and biological function over a longer term rotation through management and where relevant intervention.

SMART ROTATIONS PRINCIPLES

- A fundamental principle of SMART ROTATIONS is to eliminate breaks in the plant fungus carbon link
- Plan microbial strategy over rotation plan, e.g. seek to reduce periods of completely fallow land
- Intercrop where possible non mycorrhizal associating crops with legumes
- Inoculating with PGPR, on non mycorrhizal fungi associating crops, boosts the soil's beneficial microflora and promoting plant growth.

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